

EXHIBIT A



Ullmann's Encyclopedia of Industrial Chemistry

2. Steam Reforming of Natural Gas and Other Hydrocarbons

In the steam reforming process hydrocarbons are catalytically converted by reaction with steam into hydrogen and carbon oxides. This is the most common method for producing hydrogen or hydrogen: carbon oxide mixtures in the manufacture of important basic chemicals (e.g., ammonia and methanol), oil refining, and in many other industrial applications (e.g., iron ore reduction, hydrogenation of fats, production of oxo alcohols). Nowadays natural gas predominates by far as a feedstock over other hydrocarbons (e.g., naphtha, LPG, refinery gases) or coke oven gas which are used only under special circumstances.

The catalytic steam reforming process in tubular furnaces was invented in 1926–1928 by BASF [7]. This process was applied in the United States for the first time in the early 1930s at two commercial plants: (1) to produce hydrogen from natural gas for hydrogenation purposes and (2) to synthesize ammonia. The process was conducted under low pressure (0.4–1 MPa) and at temperatures close to 800 °C until the early 1950s; pressures up to 4 MPa and temperatures up to 950 °C are used today.

A special type of steam reforming which has been in use even earlier than tubular steam reforming is *autothermal reforming*, also called *catalytic partial oxidation*. This process differs from catalytic steam reforming in that the required reaction heat is not supplied from outside (furnace) but by internal partial combustion of the feedstock with oxygen or air, admixed to the process feed. As autothermal reforming is carried out in refractory-lined vessels (cold shell), higher pressures can be applied than in tubular steam reforming. Outlet temperatures up to 1000 °C are usual. Due to the additional expenditure for oxygen supply and safe process control this technology was of minor general importance in the past. Of common use, however, is the process modification with air as oxidant in ammonia synthesis. More recently, the oxygen based gasification has been introduced into methanol synthesis. "Combined reforming", a combination of tubular and autothermal reforming, is recognized as the most efficient syngas technology for large scale methanol plants at the moment.